DESCRIPTION OF THE DRAWINGS

Other features are inherent in the methods and systems disclosed or will become apparent to those skilled in the art from the following detailed description of embodiments and its accompanying drawings.

Fig. 1 shows a four-wheeled car driving on a road with surface unevenness;

Fig. 2 is a schematic view of an embodiment of a wheel speed sensor;

Fig. 3 shows two typical wheel speed signals which were re-sampled to the time domain;

Fig. 4 shows the coherence function of the signals in Fig. 3 which is indicative of the frequency spectrum of the signals; Fig. 4a corresponds to the front-left wheel; Fig. 4b to the front-right wheel; Fig. 4c to the rear-left wheel; and Fig. 4d to the rear-right wheel;

Fig. 5 shows an estimated correlation function of the signals in Fig. 3

Fig. 6 shows the coherence function of the signals in Fig. 3 indicative of the correlation at each frequency; Fig. 6a correlates front-left and rear-left wheels; Fig. 6b correlates front-right and rear-right wheels.

Fig. 7 shows the auto-correlation function of the signals in Fig. 3;

Fig. 8 shows the absolute value (upper plot) (Fig. 8a) and the phase value (lower plot) (Fig. 8b) of the ratio of the Fourier transformed wheel speed signals of the front-left and rear-left wheels. A straight line is fitted to the curve in the lower plot whose slope is a measure for the time delay in the corresponding wheel speed signals;

Fig. 9 shows, similarly to Fig. 3, two typical wheel speed signals which were re-sampled to the time domain, now with varying speed;

Fig. 10 shows a schematic block diagram of the system for determining the velocity of a vehicle;

Fig. 11 shows a block diagram of the method scheme of determining the velocity of a vehicle

which gives

$$\hat{r}_3 = \arg\max_r \bar{R}_{13}(\frac{B}{r}) \,. \quad (9)$$

Proceeding with the right side of the vehicle in a similar way yields $\hat{r}_2$ and $\hat{r}_4$.

Since it is known that the wheel radius does not deviate very much from the nominal wheel radius r_{nom} it is sufficient to estimate $\bar{R}_{13}(x)$ on a grid close around B/r_{nom}. The finer the computed grid is, the better is the potential accuracy in determining $\hat{r}_i$.

In summary, this embodiment allows to estimate all wheel radii r_i of the vehicle even at rapidly varying vehicle velocities. From these wheel radii r_i the absolute velocity $v_i = \omega_i r_i$ at each wheel can be determined and simple geometrical transformations can be used to find the velocity at any position of the vehicle.

Resolution Enhancement

The resolution in determining the position of the peak in the correlation function determines the resolution of the final wheel radius measurement respectively the velocity measurement. In reality, the functions $\omega_i(t)$ are not continuous time functions. Instead, they are discrete functions and their time resolution is mainly determined by the cog spacing of the cog-wheel in the ABS-sensor. Since a typical axle spacing of a car is $B = 3\,\text{m}$ and a typical wheel radius is roughly $r = 0.3\,\text{m}$ the peak of $\bar{R}_{13}(x)$ typically occurs for approximately $x = B/r_{nom} \approx 3/0.3 = 10$ which corresponds to approximately $BL/(2\pi r) \approx 3 \cdot 50/2 \cdot 75$ cogs for an ABS sensor with a cog-wheel with $L = 50$ cogs. In principle, the resolution which is obtainable when r is determined is limited by this cog separation. Estimating for example 76 instead of 75 cogs for the correlation peak position results in an radius error of approximately 1.3%. In the following,

$$r_i = \frac{B}{t_k^1 - t_i^1} . \qquad (20)$$

System and Computer Program Product

The embodiments of the computer program products with program code for performing the described methods include any machine-readable medium that is capable of storing or encoding the program code. The term "machine-readable medium" shall accordingly be taken to include, but not to be limited to, solid state memories, and optical and magnetic storage media. The program code may be machine code or another code which can be converted into machine code by compliation and/or interpretation, such as source code in a high-level programming language, such as C++, or in any other suitable imperative or functional programming language, or virtual-machine code. The computer program product may comprise a data carrier provided with the program code or other means devised to control or direct a data processing apparatus to perform the method in accordance with the description. A data processing apparatus running the method typically includes a central processing unit, data storage means and an I/O-interface for signals or parameter values.

Thus, a general purpose of the disclosed embodiments is to provide improved methods and products which enable to more accurately determine a vehicle's velocity by means of wheel speed sensors which are in particular already existing within common vehicle electronic systems (antilock braking system and the like).

All publications mentioned in this specification are herein incorporated by reference.

Although certain methods and products constructed in accordance with the teachings of the invention have been described herein, the scope of coverage of this patent is not limited thereto. On the contrary, this patent covers all